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Evolution and Conservation of Biological Diversity in South American Headstanding Fishes

Overview:

Biodiversity conservation remains a pressing environmental concern in tropical South American rivers, where habitat degradation and encroaching civilization threaten the world's greatest diversity of freshwater fishes. Effective conservation strategies depend critically on accurate and biologically meaningful measures of diversity. This study develops a novel method for quantifying one type of biodiversity (morphological diversity) and applies that method to understand the evolutionary origin and geographic distribution of morphological diversity in two closely related groups of South American headstanding fishes. Two overarching questions are addressed:

1) Evolution: Why is biological diversity distributed unevenly across the tree-of-life? How and why have some groups of organisms evolved extraordinary anatomical variation while other groups contain many species that look and act similar?

2) Conservation: Does species richness accurately predict morphological diversity in different geographic regions? Will conservation strategies designed to preserve many species tend to protect the most distinctive species as well?

Study System

Figure 1: Three anostomoid skulls. *Leporinus mormyrops* (top), *Gnathodolus bidens* (middle), *Leporinus fasciatus* (bottom)

- Two **sister-clades**
  - Anostomoidea (Figure 1) and Curimatoidea (Figure 2)
- Related to pirahnas and tetras
- Anostomidea: **highly diverse**
  - 130 species
  - Highly variable teeth and jaws
  - Variable diets, specialists on plants, insects, sponges, fish scales
- Curimatoidea: **not at all diverse**
  - 110 species
  - All lack jaw teeth and eat detritus
  - All have similar jaw shapes
- Ideal system for evolutionary study
  - Monophyly, equal species richness, broad sympatry rule out unequal ages of origin, unequal net speciation rate, different environmental histories as agents of diversification
- Relevant to conservation
  - Comprise up to 90% fish harvest
  - Valued in aquarium trade
  - Many rare species

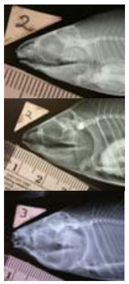

Figure 2: Three curimatoid skulls. *Steindachnerina dobula* (top), *Potamorhina altamazonica* (middle), *Prochilodus nigricans* (bottom)

Objectives and Expected Outcomes

- Develop a novel method for measuring morphological diversity
- Reconstruct a phylogeny (tree-of-life) for the Anostomoidea
- Discover undescribed species, clarify taxonomy
- Evaluate whether different or similar evolutionary processes likely produced the modern morphological diversities in the two clades
- Determine which South American regions represent centers of endemism and calculate the morphological diversity of each region
- Determine whether species richness accurately predicts morphological diversity in anostomoid and curimatoid lineages.

Measuring Diversity

- Characteristic skull shape of each species determined from location of 21 "landmarks" located around the skull (Figure 3)
- 151 species, 1257 total specimens measured
- Skull shapes treated with relative warps (principal components) analysis
- Generates a scatter of species on independent **morphospace** axes (Figure 4)
- Species near each other in morphospace are similar, distant species have very different shapes
- Morphological diversity is measured as the **variance** or **volume** of the species cloud

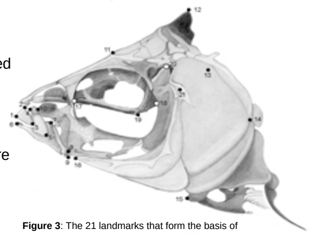

Figure 3: The 21 landmarks that form the basis of the diversity metric. Skull of *Curimatella alburna*, drawing by B. Sidlauskas

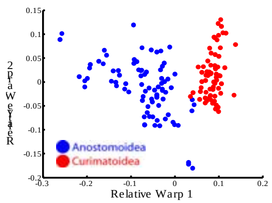

Figure 4: Morphospace plot showing the scatter, or morphological diversity of the two groups of fishes

- Results confirm the Anostomoidea to be much more morphologically diverse than the Curimatoidea, with twice the variance and six times the volume.
- **This method can measure morphological diversity in any group of organisms.**

Evolution

- Computer simulations of evolution (Figure 5) reveal that in order to achieve such hugely different morphological diversities, these groups **must have experienced different rates of morphological evolution.**
- The most likely rate of morphological change in the Anostomoidea is double that in the Curimatoidea
- **Possible explanation:** The dramatic lengthening of the quadrate bone in anostomoids may have promoted evolutionary change by relaxing a structural constraint on jaw orientation

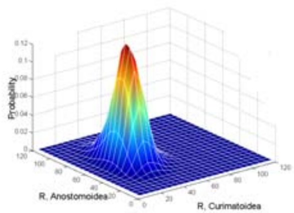

Figure 5: Likelihood surface illustrating the probabilities of evolving the Anostomoidea and Curimatoidea under various combinations of evolutionary rates (R). It is very likely that the historical rate of morphological change in the anostomoids was higher than in the curimatoids.

Phylogenetics

- Work in progress will reconstruct the tree-of-life (phylogeny) for the Anostomoidea in a collaborative project with Richard Vari, curator of fishes at the Smithsonian.
- A preliminary tree based on morphological characters appears in Figure 6.
- Phylogenetic reconstruction will permit more detailed evolutionary and biogeographic questions to be asked and answered.
- In particular, knowledge of the phylogeny will reveal when the morphological diversity of the Anostomidea began to increase greatly.

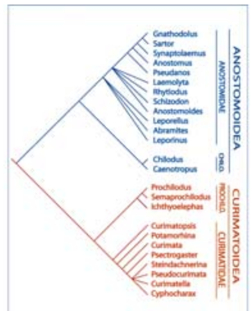

Figure 6: Preliminary phylogeny for the Anostomoidea and Curimatoidea, based on morphological data and largely complied from the work of Vari and Winterbottom.

New Species

- Three new species were discovered during this work
- Three other specimens may represent new species
- Description of *Pseudanos winterbottomi* (Figure 7) (Winterbottom's False Anostomus) is in press in Copeia

Figure 7: Holotype of *Pseudanos winterbottomi*. Drawing by B. Sidlauskas

Conservation

Figure 8: Regions of freshwater fish endemism within tropical South America. Curimatoid data drawn from the work of Vari.

- Examination of thousands of museum specimens reveals at least **13 recognizable areas of endemism** for the Anostomoidea and Curimatoidea within South America (Figure 8).
- The Amazon, Orinoco and Paraguay drainages are the most species-rich.
- Smaller, isolated drainages with few total species (Lago Maracaibo, French Guiana) frequently harbor species found nowhere else in the world

- **Species richness is a generally accurate predictor of morphological diversity.**
- However, some regions (e.g. Guyana) have more morphological diversity than would be predicted from species richness alone.
- Such centers of increased morphological diversity should be afforded increased conservation priority.

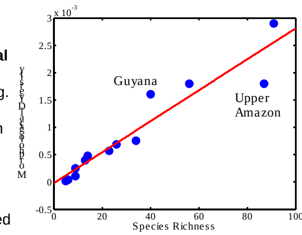

Figure 9: Positive relationship between species richness and morphological diversity (morphospace volume) in the 13 regions of endemism identified in Figure 8

Collection Building / Outreach

This research has added many new specimens and tissue samples to natural history collections in Chicago, Philadelphia and Lima, Peru.

Results are communicated to the public via the Field Museum's Scientist at the Field and Members' Night programs.

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